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Detection of *Olea europaea* subsp. *cuspidata* and *Juniperus procera* in the dry Afromontane forest of northern Ethiopia using subpixel analysis of Landsat imagery

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Abstract. Comprehensive and less costly forest inventory approaches are required to monitor the spatiotemporal dynamics of key species in forest ecosystem. Subpixel analysis using the earth resources data analysis system imagine subpixel classification procedure was tested to extract *Olea europaea* subsp. *cuspidata* and *Juniperus procera* canopies from Landsat 7 enhanced thematic mapper plus imagery. Control points with various canopy area fractions of the target species were collected to develop signatures for each of the species. With these signatures, the imagine subpixel classification procedure was run for each species independently. The subpixel process enabled the detection of *O. europaea* subsp. *cuspidata* and *J. procera* trees in pure and mixed pixels. Total of 100 pixels each were field verified for both species. An overall accuracy of 85% was achieved for *O. europaea* subsp. *cuspidata* and 89% for *J. procera*. A high overall accuracy level of detecting species at a natural forest was achieved, which encourages using the algorithm for future species monitoring activities. We recommend that the algorithm has to be validated in similar environment to enrich the knowledge on its capability to ensure its wider usage. [DOI: 10.1117/1.JRS.9.1.XXXXXX]

Keywords: subpixel analysis; Olea europaea, Juniperus procera; Desa'a forest; Afromontane.

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1 Introduction

Forests are among the crucial natural resources on earth. They are the origin of modern civilization, playing a critical role in regulating the environment. They offer sources of livelihoods, provide feedstock for different industrial products, and above all, deliver unique ecosystem services.[1,2] Their role is even more significant in developing nations where the vast majority of the population depends on forest resources for their daily consumptions. However, the ever-intensifying utilization of forest resources coupled with recurrent droughts[3] and lack of sustainable management interventions[4] resulted in severe degradation of the remnant forests of northern Ethiopia.

The ongoing shrinking of the forest size[5] and degradation in terms of species composition and vitality[6] are clear indicators. As a result, forests are being fragmented into small patches, and their structure and species composition are influenced.[5,7] These alterations are known to be

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among the main causes of diminishing biological diversity in the tropics.[6,8] Due to fragmentation and isolation processes, remnant dry Afromontane forests in the northern Ethiopian highlands are largely restricted to church yards and other sacred groves in a matrix of cropland and semiarid degraded savannah. It is believed that restoration of these valuable resources is absolutely necessary to ensure sustainable management and conservation of genetic resources.[4]

One of the major impacts of fragmentation and habitat loss is the change in species composition. Due to this process, the two characteristic species of the dry Afromontane forests of Ethiopia,[9] *Olea europaea* subsp. *cuspidata* (olive) and *Juniperus procera* (juniper), are being replaced by encroaching and light demanding shrubs such as *Cadia purpurea* and *Tarchonanthus camphoratus*.[3,6] This will critically diminish the ecological importance of these species and their role as source of seed and propagules to be used for future restoration programs. Moreover, the extinction of such locally important species will be inevitable if appropriate interventions are not taken in time.[4] A number of studies have been conducted on such remnant forest reserves[3,6,10,11] stressing the severe state of forest degradation and habitat loss. However, aside from general assessment of forest degradation, no actual inventory has yet been made on the extent of the most valuable key species of the forest. There is a need for such studies to prepare for the timely action of forest conservation before they are irreversibly degraded. Moreover, they will be an important component of any biodiversity conservation strategic plans.[7,12]

In practice, it is very difficult to inventory tree species over large and mountainous areas with ground surveys, especially when human and budgetary resources are limited. A possible alternative approach consists of using remote sensing imagery, as it can deal with large geographic areas with reasonable effort and accuracy.[13] Remotely sensed imagery is frequently used in the field of forest science for the classification of forest types and the detection of cover changes[14–16] for biodiversity assessment,[17] wetland mapping,[18] forest canopy closure,[13] and rangeland degradation assessment.[19]

Different image data classification algorithms are in use which can be assigned to one of a traditional per-pixel classification and subpixel classification.[18,20] The per-pixel classification approaches use reflectance data stored per pixel and representing the combined reflectance of all features present within that pixel.[21] For example, a Landsat image with a pixel area of 900 m^2 (30 m $\times$ 30 m) typically covers different features such as trees, bare land, and grassland. In the traditional classification method, these three distinct features are assumed to represent a single feature with a reflectance value that entails the averaged reflection of all components (here, trees, bare land, and grassland).[22] In most cases, natural phenomena occur in a mixed pattern. For instance, natural forests are composed of different species, open areas, grasslands, and bare soils. Hence, remote sensing image analysis is better applied in recognizing the presence of such mixed geographical features within single pixel.[23] The study area, Desa'a forest, is a natural forest with recorded species composition of 149 trees, shrubs, lianas, and herbs.[23] The dominant tree species are olive and juniper, which grow mixed with respect to each other and with several shrubs,[10] especially at the higher altitudes.[3,6]

A pixel containing 40% juniper, 40% olive, and 20% *Carissa edulis* may be classified as "mixed juniper-olive-carissa" because the so far known traditional classifiers are not capable of extracting information about the proportion of individual materials of interest. These classifiers use average spectral information of material within a pixel and classify pixels in an image by evaluating individual pixels for their compound spectral signature.[20,24]

An approach for doing this is subpixel processing, defined as the exploration for specific materials of interest within a pixel's mixed multispectral image reflectance spectrum.[20] Subpixel processing does not provide information on where the material of interest (MOI) resides within the pixel;[21] while providing information on the relative contribution of the MOI found within a pixel down to 20% of a pixel. This paper describes a subpixel image detection process demonstrated by classifying juniper and olive which grow in dry Afromontane forests naturally mixed with different other tree and shrub species. A successful detection of these two dominant species in the Afromontane forest environment with a subpixel classifier would be of great importance for their inventory and can be upscaled to other similar environments with minimal cost and time for providing timely information to decision makers.

2 Study Area

Desa'a forest encompasses heterogeneous landscapes responsible for the significantly different biophysical settings throughout the study site. Geographically, it is located between 39°43′E and 13°45′N (Fig. 1) having an area of 120,026 ha at an altitude between 1500 and 2500 m above sea level.[3] The forest area extends from Atsbi-Wonberta Woreda of Tigray down to south area of zone two in the Afar regional state.[3,25]

The Afromontane zones of Ethiopia cover 50% of all Afromontane areas of Africa. They naturally occur in the northern and central parts of the Ethiopian highlands, where a semiarid to subhumid rainfall regime is prevailing.[10,26] Desa'a forest, characterized as dry single dominant Afromontane forest is among the eight main forest types of Ethiopia.[10] This forest is characterized by dry climate with annual precipitation <1000 mm. Among the many species within this remnant forest, juniper and olive, are the dominant and characteristic species.

3 Methodology

3.1 *Data Acquisition*

Free georeferenced scene of Landsat 7 enhanced thematic mapper plus (ETM+) imagery of 2013 with path 169 and raw 51 was downloaded from Ref. 27.

3.2 *Image Preprocessing*

Image preprocessing is needed because of different limitations of a raw image such as lack of or improper georeferencing and radiometric distortions, topographic displacement, dark strips due to sensor failure, cloud cover, haze, and sensor malfunctions.[24] However, in this study, geometric correction was not an important issue of concern, as the image obtained was already orthorectified. Whereas, environmental problem such as cloud cover and haze environmental correction was processed. In the imagine subpixel classifier preprocessing, a mandatory task in the

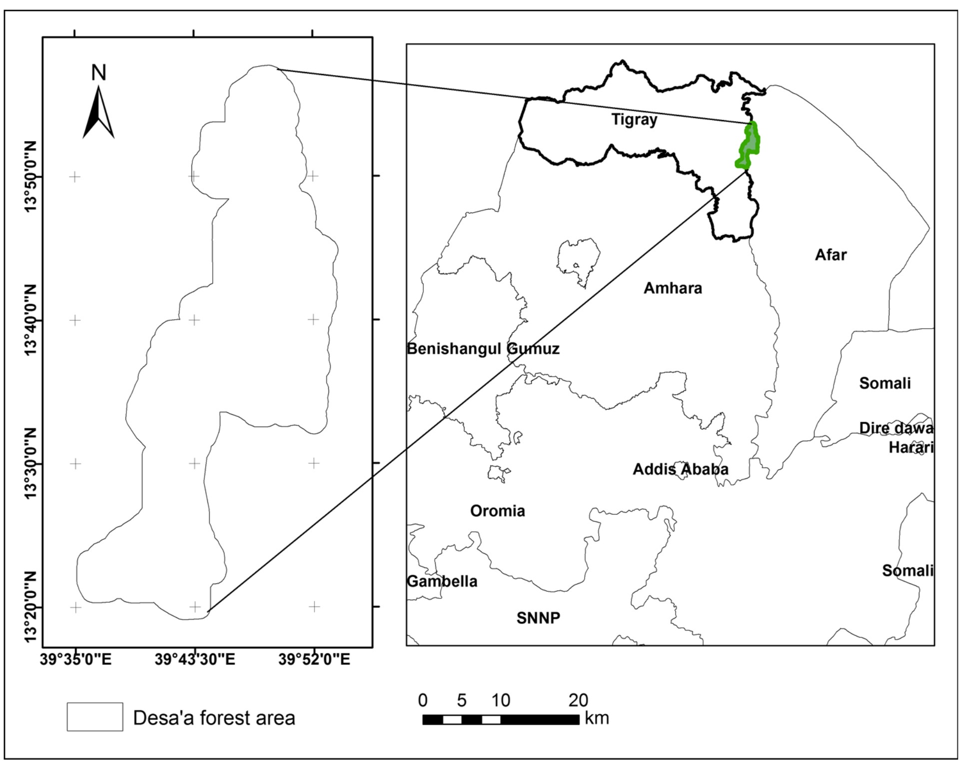

Fig. 1 Map of Desa'a forest, situated in Tigray, northern Ethiopia.

classification process, was run to identify a representative set of background spectra in the image which are used in the classification process.[20,21,28] For atmospheric correction, the fast line of sight atmospheric analysis hypercube (FLAASH) was applied in Envi SP5 environment. FLAASH works with both hyperspectral and multispectral imagery data which correct anomalies created due to atmospheric effect on the image brightness.[29] Such problems are adjacency effect (pixel mixing due to scattering of surface reflection radiance), effect of haze, aerosols and cloud, and artifacts.[30]

3.3 *Field Data Collection*

For the purpose of deriving signatures and verifying the classification, spatially well-distributed global positioning system (GPS) points were taken. For signature derivation, areas with more than 90% coverage of the matter of interests, olive and juniper, determined using hemispherical photograph were taken and used as true area of interest (AOI) and the rest were with varying areal coverage, determined by line intercept supplemented by group of forestry experts, but not less than 20% of the matter of interest which were used as valid AOI. To ensure the canopy cover sampled is at least 90% of the pixel (used as true AOI), more than $30\ \mathrm{m} \times 30\ \mathrm{m}$ continuous field of the target species to dilute the position inaccuracies were selected and hemispherical photograph was used to measure the canopy closure percentage. Likewise, mixture of the matter of interest and other features with cover percentage between 20% and 90% were collected and are used as valid AOI indicating the presence of the target species in the signature development process. Different GPS points from area where the species of interest are not represented were collected and used as false AOI. The false AOI were used during the automated signature derivation process to dictate the software to discriminate (false alarm) such occurrences from the target species[18] assisting the software to further refine the signature. Different GPS points from those used to derive signature were also collected which were mainly used for postclassification verification.

3.4 *Signature Derivation and Refinement*

Signature derivation for juniper and olive was done differently. This was because olive exhibits almost similar phenological characteristics (dark green canopy) at all ages and soil conditions, while juniper has a very light canopy color at younger age and when occurring in degraded areas and dark green color at older ages and when growing in moist and good soils. Therefore, to detect juniper, signatures of both light and dark green juniper were combined in one family using the signature combiner.[21,31] In addition, files from the environmental correction process (Table 1), which can be seen in the report file produced by the process, are used during the process of signature derivation and MOI classification.

These two variables, atmospheric correction factor (Acf) and sun correction factor (Scf) (Table 1), do have two distinct applications. The Acf is used in the signature derivation and classification process whereas, the Scf is used when an image is used to derive signature for application to imagery of different dates or scenes.[32] Signature can be derived in two ways. Either AOI can be developed by selecting individual pixels or by delineating group of pixels corresponding to known training sites. The first option was used in this case. Signature formulation was based on a user specified fraction of the pixels in the training set.[28,32]

3.5 *Subpixel Classification*

Using the preprocessed image classification for fraction representation of the MOI, here, olive and juniper, is run with the appropriate signature. This results in a thematic map

Table 1 Environmental correction file values of 2013 image by band.

Bands	1	2	3	4	5
Acf	44.348	26.378	18.685	8.122	4.277
Scf	227.939	250.125	161.125	246.167	192.593

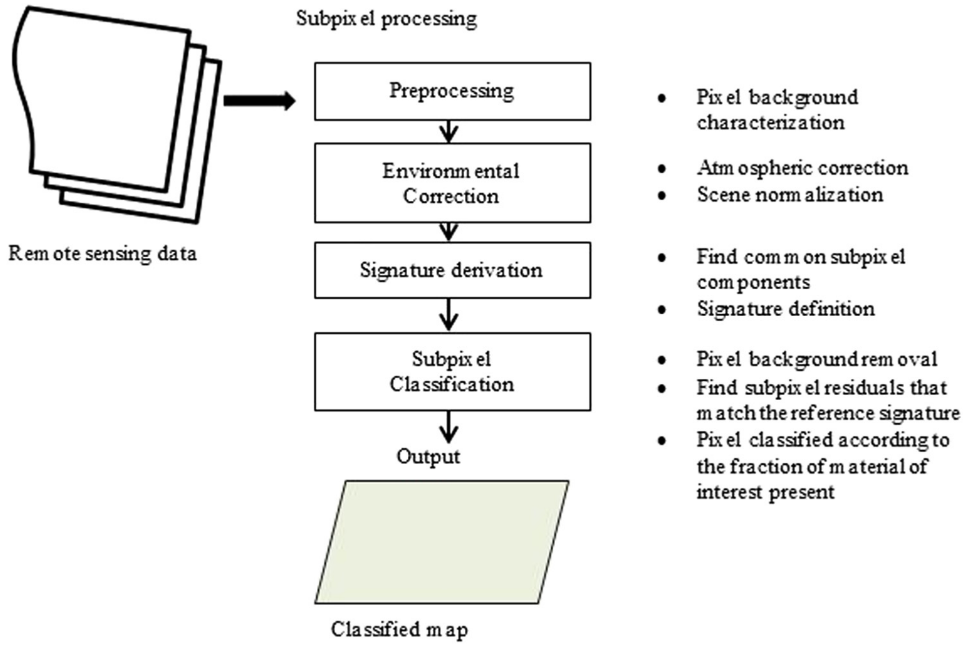

Fig. 2 Major steps in subpixel processing.

having the proportional contribution of the matter of interest. The whole process is shown in Fig. 2.

3.6 *Accuracy Assessment*

The core ambition of remote sensing image classification is that the classified images accurately represent the actualities on ground. All the activities performed before image classification such as preprocessing (georeferencing, environmental correction, and sun angle correction among many others) are meant to improve the accuracy of image classification.[24,33] Classification accuracies are found to differ with the classifier algorithm used. Accuracy assessment determines the level of relationship between the commonly referred "data signature" in the imagery and the categories the user is interested in Ref. 34. Therefore, to see how accurately the species were detected using subpixel classifier of the earth resources data analysis system imagine add on software, postdetection classification accuracy assessment was done for each species using confusion matrix. To assess the omission and commission errors, a total of 100 GCPs each were taken for olive and juniper. Fifty points were collected in the field and 50 points were picked from the classified image where continuous detections of the species were observed.[18,21] The 50 points were taken from the classified thematic map systematically (30 points from 70% to 100%, 10 points from 40% to 69%, and 10 points from 20% to 39% cover classes) so as to include different cover classes. The accuracy assessment includes both detecting the species and accurately presenting the cover percentage of the species within a given pixel. Detecting the species but not the accurate cover is considered as misclassification.

4 Results and Discussion

4.1 *Image Classification*

The subpixel analysis procedure was run setting the tolerance value at the default value (1) and the output classes at 8 using the appropriate signatures developed as described in Sec. 3. This yields a thematic map with MOI fraction ranging from 0.2 to 1.00 with a 0.1 increment (Figs. 3 and 4).

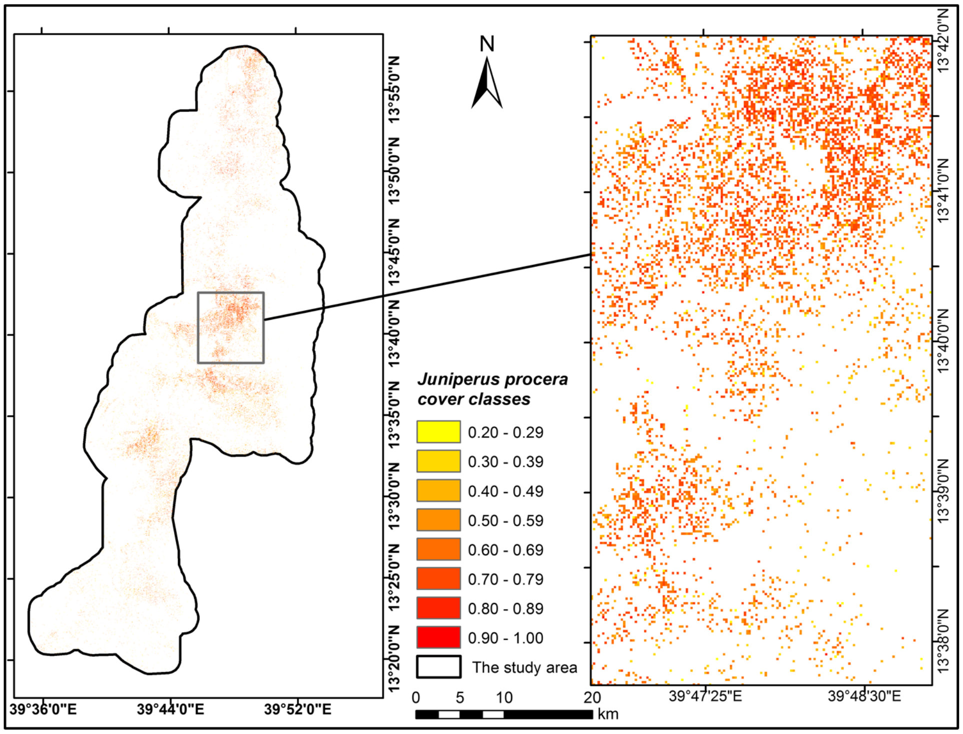

Fig. 3 Subpixel occurrences of *Juniperus procera*.

4.2 *Accuracy Assessment*

4.2.1 *Juniperus procera*

Following the procedures discussed in Sec. 3, an overall accuracy of 89% with 7% and 4% commissions and omissions, respectively, was achieved for juniper. It was found that juniper,

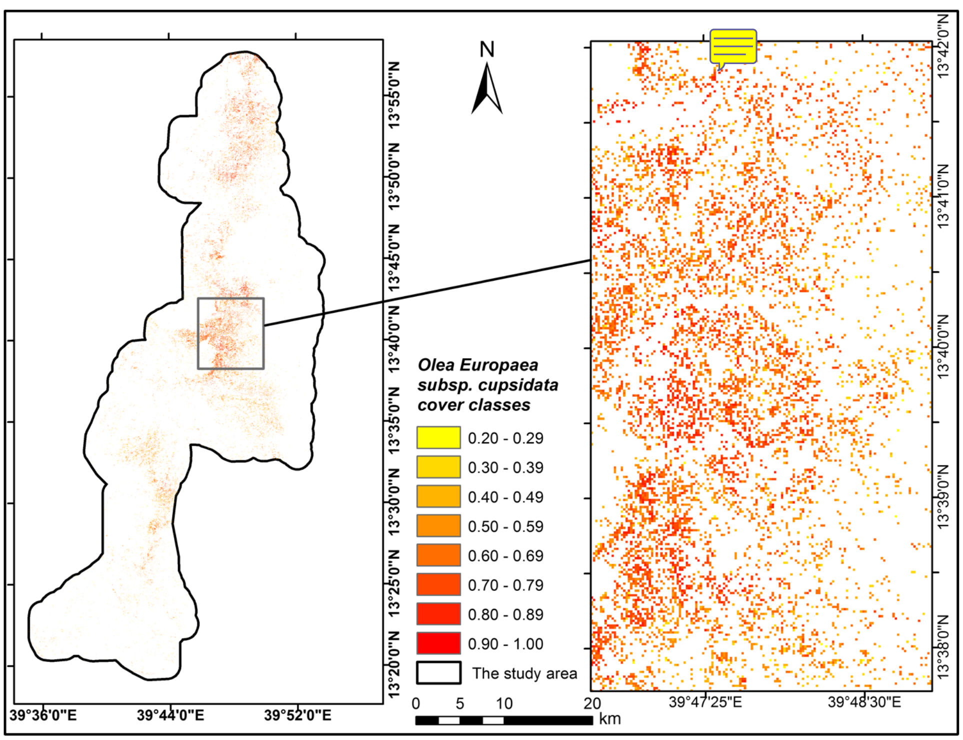

Fig. 4 Subpixel occurrences of *Olea europaea* subsp. *cuspidata*.

Table 2 Accuracy assessment of *Juniperus procera* and *Olea europaea* subsp. *cuspidata*.

Species	GCP[a]	GCP[b]	Commission	Omissions	Overall accuracy
O. europaea	41	44	9	6	85
J. procera	43	46	7	4	89

[a]Control points from map.
[b]Ground control points.

especially light green juniper, was confused with *C. purpurea*. It is worth mentioning that the level of detection accuracy was improved by using the separate seed signature of both deep and light green juniper signatures which has improved the accuracy by 10%. Similar results were obtained in Ref. 21, where the classification accuracy of bald cypress was increased by 7% using seed signature.

4.2.2 *Olea europaea subsp. cuspidata*

A similar procedure as for juniper was conducted and an accuracy of 85% was achieved with 6% and 9% omissions and commissions, respectively. Confusions were recorded with young *C. edulis* species. In all classification results, repeated ground survey was made to verify if uncertain and unexpected occurrences are observed in the classified thematic maps.

Subpixel classifier, as one of the recently evolved classifiers, accuracy assessment is made systematically different from the other traditional classifier.[35] In this study, an overall accuracy assessment of the two species yielded 85% and 89% for olive and juniper (Table 2), respectively. Comparable accuracy levels of 71% to 91% were achieved for detection of forest species in wetland ecosystems,[36] for spruce beetle infestation study,[18] and for detecting cypress and tupelo.[21]

5 Conclusion

This study investigated the capability of the imagine subpixel classifier procedure for detecting *O. europaea* subsp. *cuspidata* and *J. procera* in northern Ethiopia using Landsat 7 ETM+ imagery. This research addressed the question whether this procedure is capable of detecting individual tree species at subpixel level. This study has demonstrated the potential of subpixel analysis in mapping forest at species level with an accuracy level of 87% which is among the highest accuracy level attained with imagine subpixel classifier so far. A very careful and inclusive signature derivation greatly affects the results of the algorithm which is demonstrated by the detection level of juniper using the seed signature of young and old juniper.

Omitting stands with different physiological appearances in the signature derivation undermines resources availability. Here, using seed signature of different stands of the same species with different physiological characteristics has greatly improved the accuracy assessment. Therefore, this tool can be of great help for monitoring and creation of urgency in areas where there is high rate of environmentally and economically important species depletion such us in Ethiopia. To utilize this tool, accurate representation of signature with high precision GPS tools and the presence of matter of interest of more than 90% areal coverage of a pixel is mandatory and greatly influences the accuracy level. Equally important is the evaluation of signatures before running the classification to map the matter of interest at the highest possible accuracy level.

The subpixel classifier procedure has the potential to be helpful as it is very difficult to make vegetation inventories in large forest areas. In addition, as remnant forests in Ethiopia are only present in mountainous and inaccessible areas, where time, human resources, and budgetary constraints make it nearly impossible to cover all areas, application of the procedure would permit undertaking the whole task at reasonable effort and accuracy. The availability of such vital information would enable decision makers to timely respond to forest management needs and thereby contribute to the sustainable management of remnant dry Afromontane forests in the country.

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